

Temporary fluoride concentration changes in groundwater in the context of impact assessment in the Vaniyar sub-basin, South India

S. Satheeshkumar¹ · S. Venkateswaran¹ · R. Kannan¹

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Abstract India's surface water and groundwater distribution is temporally variable due to the monsoon. Agriculture is one of the dominant economic sectors in India. Groundwater quality is regularly assessed to determine usability for drinking and irrigation. In this study, World Health Organization and Bureau of Indian Standards guidelines were used to determine suitability of groundwater near artificial recharge structures (ARS) with a focus on the structure's impact on groundwater quality. Groundwater resources were evaluated for irrigation suitability using electrical conductivity (EC), sodium adsorption ratio, the US Salinity Laboratory diagram, sodium concentration, Wilcox's diagram, Kelly's index, and Doneen's permeability index. EC and major ions were tested in recharge areas at different distances from the ARS. The construction of ARS at optimal distances along major streams has improved groundwater quantity and quality in the sub-basin. Before construction of ARS, fluoride concentrations were higher; after construction, fluoride was reduced in most locations. Water stored in the check dam and groundwater in the wells closer to the structure were suitable for both drinking and irrigation purposes. Impact of ARS on nearby groundwater quality was observed at Pallipatti, Mulayanur, Venkadasamuthram, Pudupatti, Poyyappatti, Harur1, and Sekkampatti. More distant sites

included Pappiredipatti, Nambiyappati, Menasi, Harur, Todampatti, and Adikarapatti. Data demonstrated improved groundwater quality in the area of the ARS. Through recharge, the non-potable fluoride in the region is reduced to the permissible limit for human consumption.

Keywords Drinking purposes · Salinity · Check dam · Fluoride · Dental fluorosis

1 Introduction

Most groundwater recharge in Tamil Nadu is from rainfall associated with the northeast monsoon. Groundwater development has accelerated in recent years, giving rise to the practice of managed aquifer recharge. The suitability of groundwater resources for drinking depends on various constituents, such as major and minor ions and dissolved inorganic, organic, radiological, and biological constituents. The Bureau of Indian Standards (BIS 2003) and the World Health Organization (WHO 2006) have prescribed permissible limits for various dissolved ions in water. In India, various groundwater recharge studies have been carried out based on these standards. Several researchers have discussed the mediating impact of artificial recharge structures (ARS) on groundwater fluoride concentrations (Patel 2002; Mudrakartha 2003; Bhagavan and Raghu 2005; Gale 2006; Palanisami et al. 2006; Bijukumar and Abraham 2009; Samarah et al. 2009; Venkateswaran 2010; Brindha and Elango 2012; Renganayaki and Elango 2013, 2014; Venkateswaran et al. 2015; Pazand 2016). Water quality is important not only in drinking water, but for irrigation as well—to ensure maximum yield from the crops. The concentration of dissolved ions must remain below the recommended permissible

✉ S. Satheeshkumar
aiswarkumar2781@gmail.com

S. Venkateswaran
geosvenkat@periyaruniversity.ac.in

R. Kannan
georkannan@mail.com

¹ Department of Geology, Periyar University, Salem, Tamil Nadu 636011, India

limits to ensure acceptable quality for drinking and irrigation. ARS are the most common form of water conservation, indirectly recharging aquifer systems in the sub-basin. In order to meet local water demand, ARS are constructed to store significant amounts of water. Existing ARS may impact groundwater quality irrespective of drainage systems and catchment areas. At present, the momentum is towards using monsoon runoff to recharge depleting aquifers, with no consideration for the water quality of the source water (Chadha 2014). Poor water quality can cause the recharging well to clog and the aquifers to become polluted with pathogens, causing water-borne diseases in the sub-basin. Additionally, various materials in the de-silting chambers can cause water quality problems to the recharged aquifers.

1.1 Details of study area

The study area is in the Vaniyar sub-basin of the Ponnaiyar River basin, southern India (Fig. 1). The Vaniyar River flows northeastward in the Dharmapuri district of Tamil Nadu. The amount of rainfall during the Southwest Monsoon is typically high, but can be highly variable. Major and minor ARS were constructed across major streams in the sub-basin. Rainfall is the major source of groundwater

recharge in the sub-basin. Agricultural activity takes place throughout the year, and depends mainly on groundwater resources from dug wells and bore wells. The Tamil Nadu Water Supply and Drainage Board tap groundwater to supply water to the houses in nearby villages. The residents also use centrifugal pumps to tap additional groundwater for domestic purposes. Geologically, the study area is underlain mainly by charnockite and epidote-hornblende gneiss.

2 Methods and data collection

Historical groundwater quality data were collected from the public works department (PWD). To supplement historical data, samples were collected in the monsoon season and the wells were concurrently inspected to assess the well type. Groundwater samples were collected from in and around ARS in the sub-basin, and analyzed for pH; electrical conductivity (EC); and calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, fluoride, and sulfate concentrations. Groundwater level and EC were measured in all wells. Representative wells at various distances from the ARS were chosen for periodic evaluation.

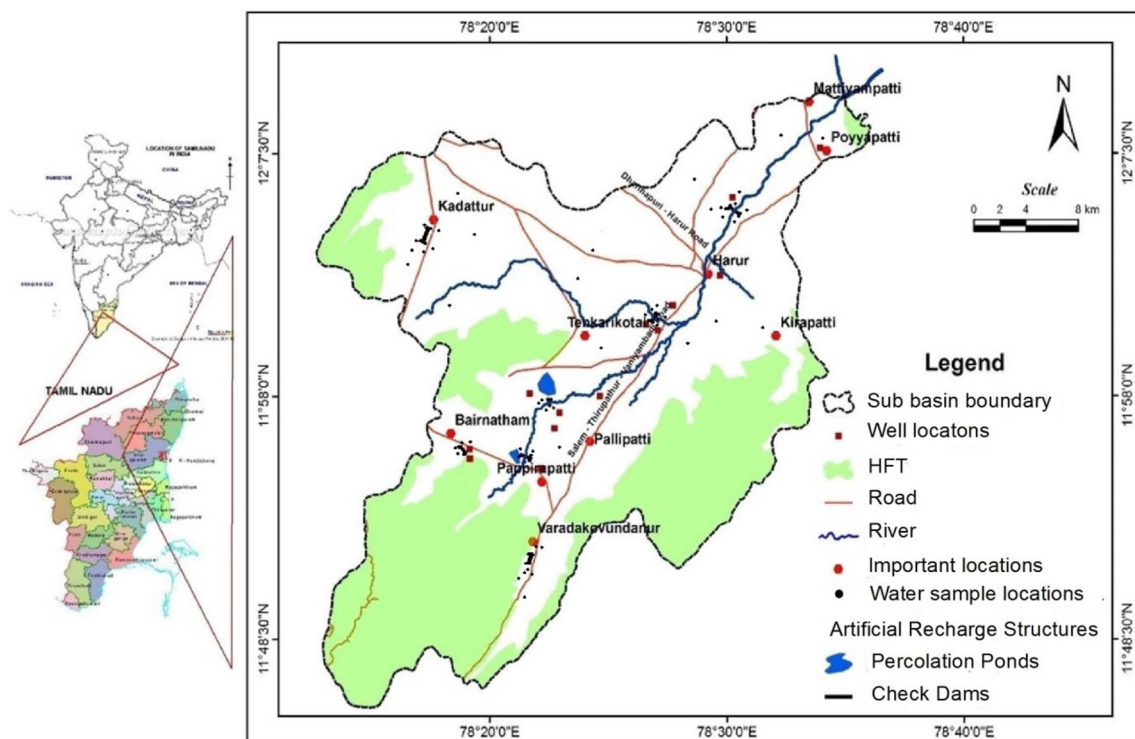


Fig. 1 Map showing artificial recharge structures with monitoring wells

3 Results and discussion

Groundwater quality was assessed for suitability for drinking based on fluoride and pH concentration across a diverse region of the study area as shown in Fig. 2. Historical data suggest fluoride in excess of the permissible limit can be attributed to over-withdrawal of groundwater and scarcity of rainfall. There was an increase in pH versus fluoride in some locations in the summer season and changes in fluoride were observed at Menasi, K. Vetripatti, and Kadattur. The worst water quality was observed at Kadattur in 2008 due to low rainfall. Fluoride and TDS concentration (Fig. 3), which are low value region indicated dilution in groundwater during rainy season. Minimum, maximum, and average of various parameters in groundwater quality are shown in Table 1.

Recharge areas were identified from the check dams in the region through assessment of total dissolved solids (TDS) and major ion concentrations (Renganayaki and Elango 2013). It is essential to safeguard water used for drinking and irrigation purposes. Maximum and minimum fluoride concentration are shown in Fig. 4. Both Salur and Kadattur recorded values >3 ppm, with values increasing with distance from the check dam.

3.1 Fluoride concentration

Analysis of groundwater samples revealed concentrations of fluoride in excess of permissible limits for drinking (Fig. 4). In most cases, the source is thought to be dissolution of fluoride-bearing minerals in granites and gneisses in the study area. It was also observed that deeper groundwater was more prone to fluoride contamination in comparison to the shallow weathered zone. High fluoride in groundwater due to the geologic environment is a considerable health problem in India and essential remedial measures are needed to combat an increasing occurrence of fluorosis, both dental and skeletal (CGWB 2008). TDS concentration decreased in groundwater by rainy season (Fig. 5).

3.2 Rainfall influence

Rainfall is a crucial climatic factor that influences water resources in seasonally variable parts of the world and its analysis an important prerequisite for agricultural planning in India (Alaka 1986). South India is a sub-tropical region where agriculture depends on monsoon rainfall, with more than 75% of rainfall occurring during the monsoon season. Monsoon rainfall is uneven both in time and space—important factors in groundwater recharge analysis. In 2008, with particularly low rainfall, Figs. 6, 7, and 8 indicate fluoride concentrations increased due to reduced recharge.

3.3 Groundwater quality for drinking purposes

Various parameters of groundwater quality are shown in Table 1. The abundance of major cation concentration in groundwater is $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$, while that of anions is $\text{HCO}_3 > \text{Cl} > \text{SO}_4 > \text{CO}_3$. The groundwater from near the ARS was of Na–Cl type. The average pH of groundwater around ARS was 7.49 and beyond in the check dam, it was 7.53. EC and TDS are important parameters, as prolonged use of drinking water with high EC may cause gastrointestinal irritation for humans (Singh et al. 2008). The EC of the groundwater samples in the study area ranged from 213 to 5162.67 $\mu\text{S}/\text{cm}$ with an average of 1627.7. The prescribed limit of EC is 1500 $\mu\text{S}/\text{cm}$. The water quality types (Piper 1944) can be quickly identified by the location of points in different zones of the diamond shaped field (Fig. 9).

The suitability of groundwater for drinking purposes depends on pH and major ions remaining under the limits suggested by WHO (2006) and BIS (2003). After construction of ARS, pH and bicarbonate and sulfate concentrations in groundwater were found to be within the permissible limits as per WHO and BIS guidelines.

The minimum, maximum, and average total hardness were 134 (at Gopinathampatti), 1588 (at Samiyapuram), and 490.9 mg/L, respectively. The groundwater samples collected around ARS are shown in the Durov diagram (Fig. 10). Some drinking water samples in case 1 are Ca- and SO_4 -dominant, commonly indicative of recharge water in gypsiferous deposits; a mixed water or water exhibiting simple dissolution may be indicated. In case 2, there are no dominant anions or cations, indicating simple dissolution or mixing. In case 3, Cl and Na are dominant cations, indicating that the groundwater is related to reverse ion exchange of Na–Cl waters. In case 4, Cl and Na dominance normally indicate end-points of waters.

3.4 Groundwater quality for irrigation purposes

The pH of groundwater and water in the check dam was less than the prescribed 8.2 maximum limit for irrigation purposes (Ayers and Westcot 1994). EC is another important parameter to determine the quality of water for irrigation purposes. The water stored in the check dam was classified as good.

3.5 Sodium adsorption ratio

Excessive sodium in water reduces infiltration rates, causing adverse effects on soil aeration and seed germination, increasing weed growth, and promoting mosquito

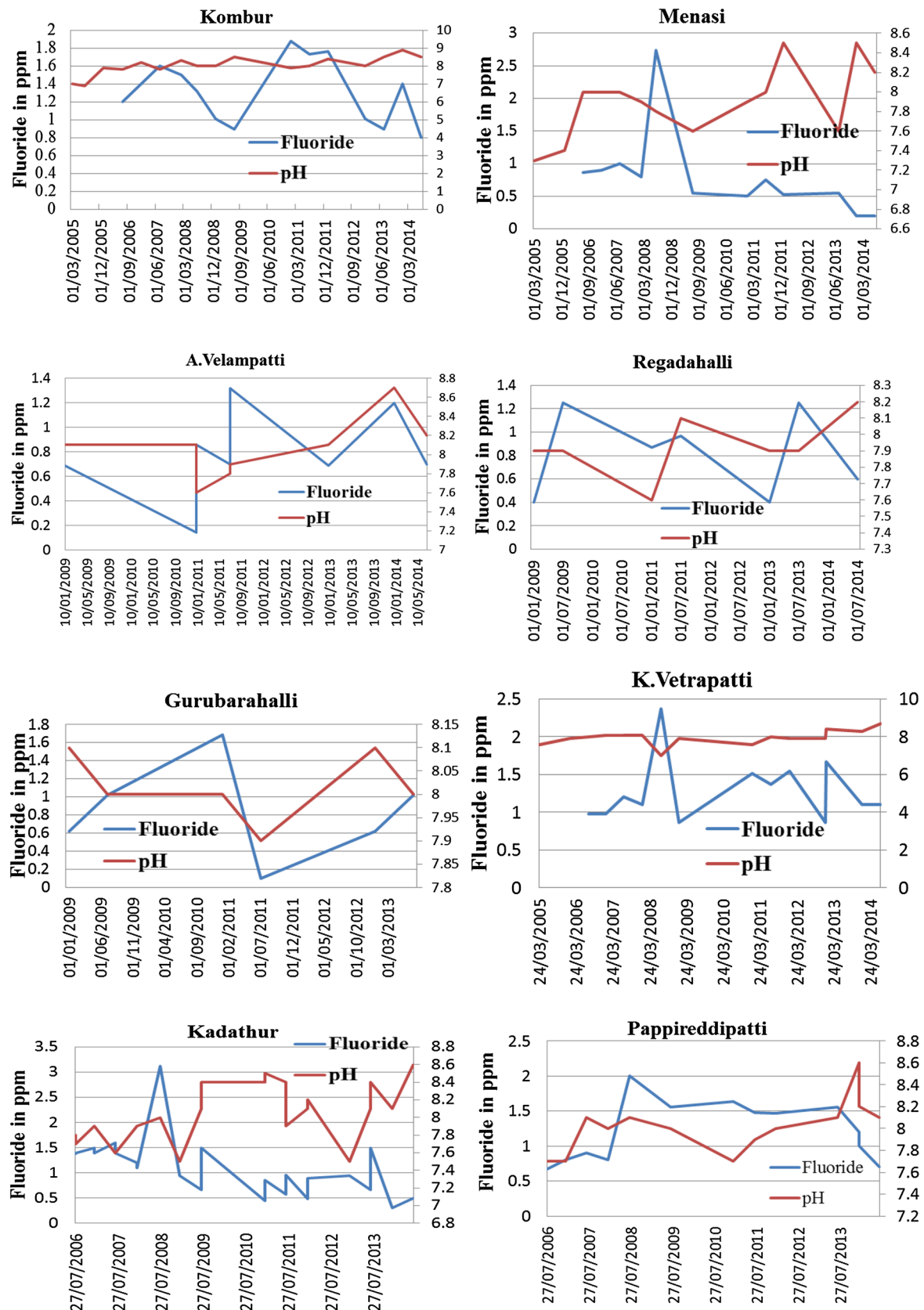
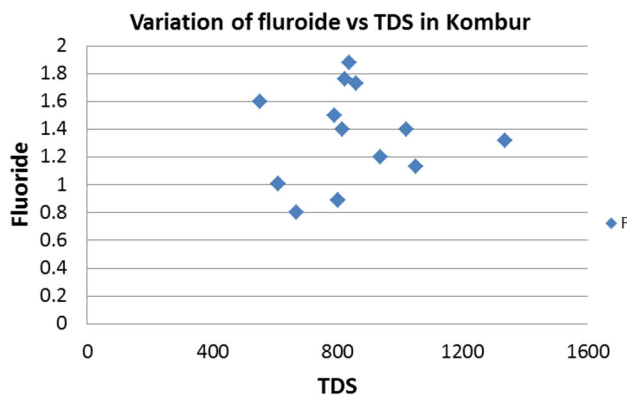


Fig. 2 Temporal variation in pH and fluoride concentration

Table 1 Minimum, maximum, average, and limit of various parameters in groundwater samples

Parameter	Minimum	Maximum	Average	Standard maximum ermissible limit (BIS 2012)
pH (–)	7.5	9.02	8.222738	6.5–8.5
EC (μS/cm)	399.19	5162.67	1627.706	NA
TDS (ppm)	119.55	2460.9	770.0923	2000
Total hardness (mg/L)	134.9411	1588.062	490.9076	600
Ca (mg/L)	18	341	100.6667	200
Mg (mg/L)	20	179	58.18988	100
Na (mg/L)	5	530	126.631	200
K (mg/L)	0	141	16.36429	10
CL (mg/L)	16	1180	217.8452	1000
F (ppm)	0	3.4	1.042024	1.5
SO ₄ (mg/L)	6	169	67.30952	400
NO ₃ (mg/L)	1	88	24.47619	0.3
HCO ₃ (mg/L)	67.1	692	343.3924	NA

**Fig. 3** Fluoride versus TDS variation at Kombur. Data from 2005–2014

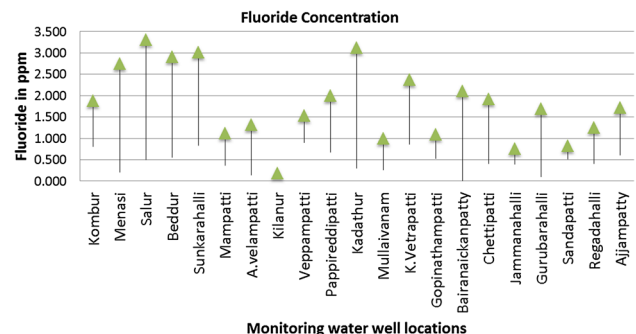
breeding due to waterlogging. The sodium adsorption ratio (SAR) helps to identify the sodium hazard.

According to Richards (1954), SAR is expressed in milliequivalents per liter as:

$$SAR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})/2}$$

The classification of water samples from the study area based on SAR is given in Table 2. All water samples fell into the excellent category with respect to SAR, indicating there is no sodium hazard. The groundwater samples were classified into four types based on the United States Salinity Laboratory (USSL 1954) diagram (Fig. 11).

As shown in Fig. 11, 65% of all the groundwater samples fell into the C3–S1 type (high salinity and low sodium). The groundwater stored close to the ARS is two types: C2–S1 (medium salinity and low sodium) and C3–S1 (high salinity and low sodium water), both of which are suitable for irrigation.

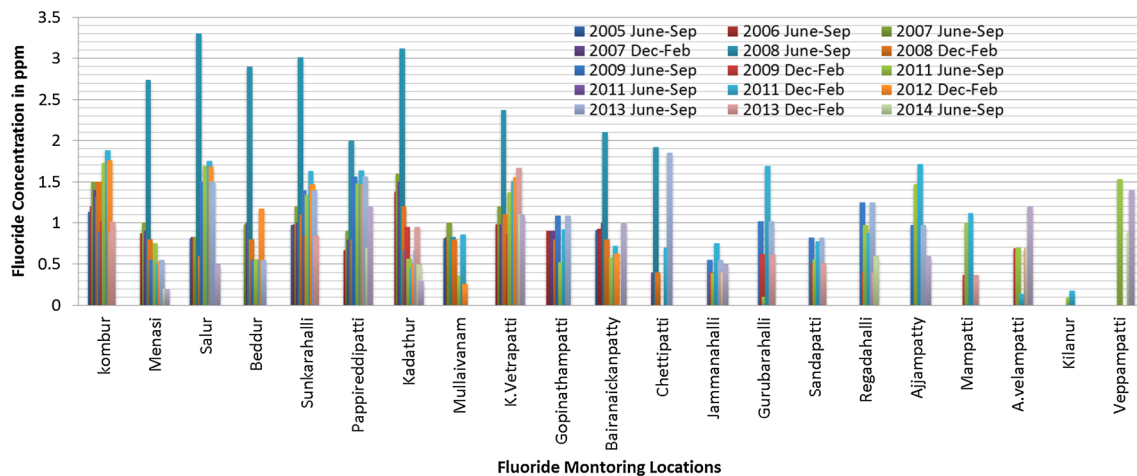
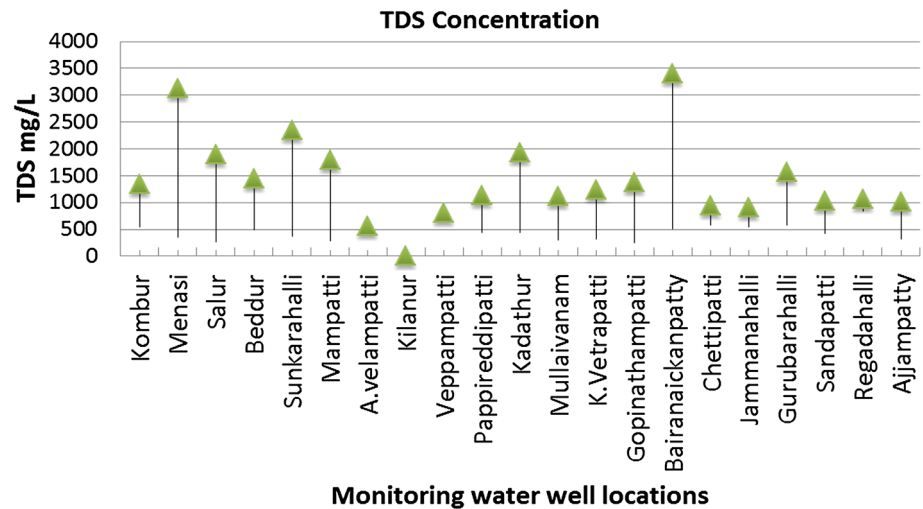
**Fig. 4** Fluoride concentration in groundwater monitoring wells

3.6 Percentage sodium

It is important to classify irrigation water based on exchangeable sodium because excessive sodium affects both soil and crops, as explained earlier. In addition to SAR, percent Na is used to determine the effect of sodium. Percent Na is calculated using the formula:

$$Na^+ \% = \frac{Na + K}{(Ca + Mg + k + Na)}$$

where all concentrations are in milliequivalents per liter. The classification of water samples based on percent Na is given in Table 3. Of the groundwater samples, 8% were classified as excellent and 80% as good. Groundwater samples collected from in and around the ARS for groundwater quality were evaluated based on Wilcox's (1955) plot, with the following samples achieving excellent ratings: Pappireddipatti, Nambiyampatti, Menasi, Pudupatti, Harur, Poyyappatti, Toddampatti, Harur1, Adikarapatti, and Sekkampatti (Fig. 12).

Fig. 5 TDS concentration in groundwater monitoring wells**Fig. 6** Fluoride concentrations in monitoring locations by monsoon season

3.7 Kelly's index

Kelly's Index (KI) is based on the ratio of sodium to calcium and magnesium and is calculated using the following formula (Kelly 1963):

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})}$$

where all the ionic concentrations are expressed in milliequivalents per liter. Less calcium creates soil dispersion, which reduces the infiltration rate. The groundwater was classified based on KI as suitable in Nambiyampatti; marginal in Pappireddipatti, Sekkampatti and Poyyappatti; and unsuitable in Mulayanur, Adikarapatti, Harur1, Menasi, Harur, Pudupatti, Pallipatti, and Venkadasamuthram. Groundwater samples collected near the ARS were classified as marginally suitable for irrigation.

Concentrations of calcium and magnesium were used to calculate total hardness. The classification of groundwater based on hardness was suggested by Sawyer and McCarty (1967). Groundwater in this area was classified as moderately hard in Nambiyampatti, hard in Pappireddipatti, Poyyappatti, and Sekkampatti; and very hard in Pallipatti, Mulayanur Venkadasamuthram, Menasi Harur, Toddampatti, Harur1, and Adikarapatti. The minimum, maximum, and average were 133.1, 615, and 354.6 mg/L, respectively. The groundwater samples collected around ARS were suitable for drinking based on major ion concentrations.

3.8 Impact of artificial recharge structures on groundwater quality

In the study area, the quality of groundwater, based mainly on fluoride concentration, has been improved through

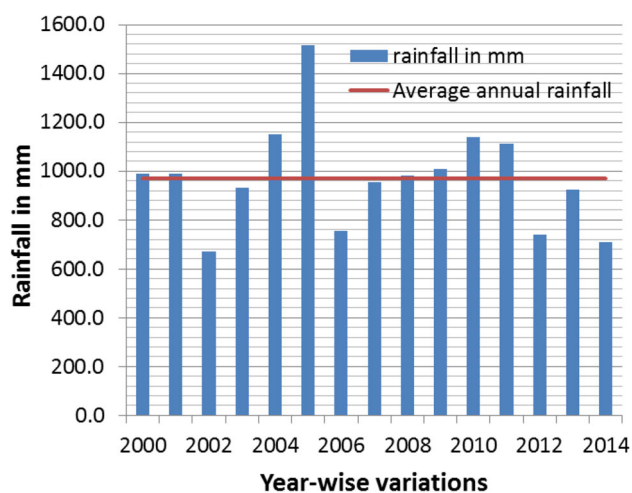


Fig. 7 Average annual rainfall variation

dilution within about a 500 m radius of ARS (Fig. 13). Increased groundwater quality also improves the quality of soils; as a result, many farmers have benefited from ARS. Fluoride concentration was reduced in groundwater after construction of a check dam (Bhagavan and Raghu 2005), studied in Andhra Pradesh, India. Bijukumar and Abraham (2009) observed high concentrations of ions upstream in Peringottu Kurissi, India. Gale (2006) also noted improved groundwater quality in Satlasana, India, as did Mudrakartha (2003) in Gujarat, India. Salinity, arsenic, fluoride, and boron were diluted due to increased recharge. Palanisami et al. (2006) found ionic concentrations were reduced near a check dam in Tamil Nadu, India. Samarah et al. (2009) suggested the dilution of ions they observed was

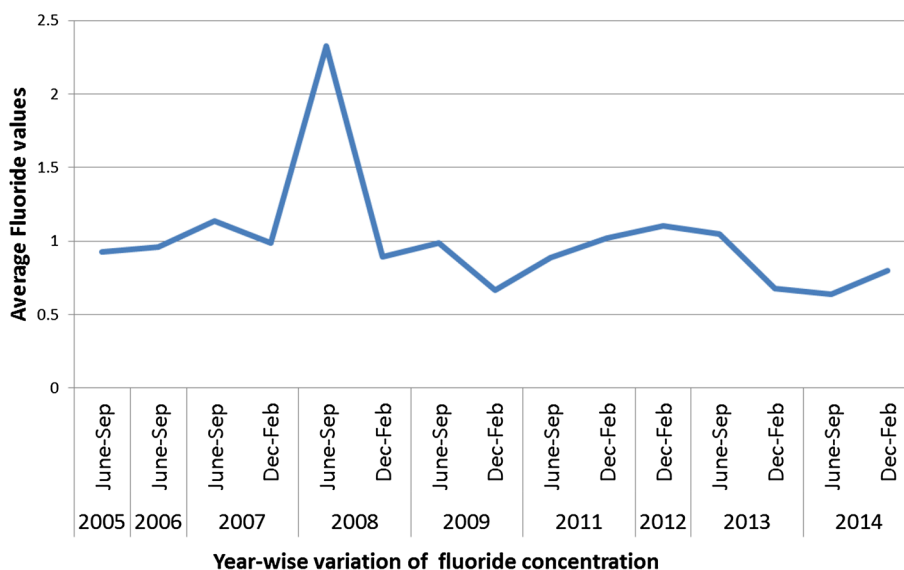
due to the presence of a check dam in Wadi Feifa, Jordan. Parimala Renganayaki and Elango (2013) reported dilution of EC, Na, and Cl in the groundwater near a well in Chennai, Tamil Nadu, India. In dilution through ARS, groundwater is improved at a rate much higher than under natural conditions through rainfall percolation during the monsoon.

Impact assessments of ARS on dilution of fluoride concentration in groundwater have been evaluated in the study area. Groundwater resources within 500 m of the ARS benefited from improved water quality in Pallipatti, Mulayanur, Venkadasamuthram, Pudupatti, Poyyappatti, Harur1, and Sekkampatti. All of these locations were identified as having safe drinking water, in contrast with more distant locations in Pappiredipatti, Nambiyappati, Menasi, Harur, Todampatti, and Adikarapatti. After the construction of ARS, reduced fluoride in groundwater was observed at Venkadasamuthram in the sub-basin. Bhagavan and Raghu (2005) also reported reduced fluoride concentrations in groundwater after construction of a check dam.

The EC and concentration of major ions were analyzed in both the benefited and non-benefited regions (Figs. 14, 15). Monitoring wells assessed for impact of ARS indicate a decrease in concentration of ions in groundwater due to recharge water. Due to low recharge beyond the selected ARS, no significant improvement in groundwater quality was observed in the region in terms of EC versus chloride.

Evaluation of groundwater quality recharged by ARS was conducted at Pallipatti, Mulayanur, Venkadasamuthram, Pudupatti, Poyapapatti, Harur, and Sekkampatti. More than 500 m from ARS, water quality was not benefited at Pappiredipatti, Nambiyampatti, Menasi, Harur1,

Fig. 8 Year-wise average fluoride (ppm) variation



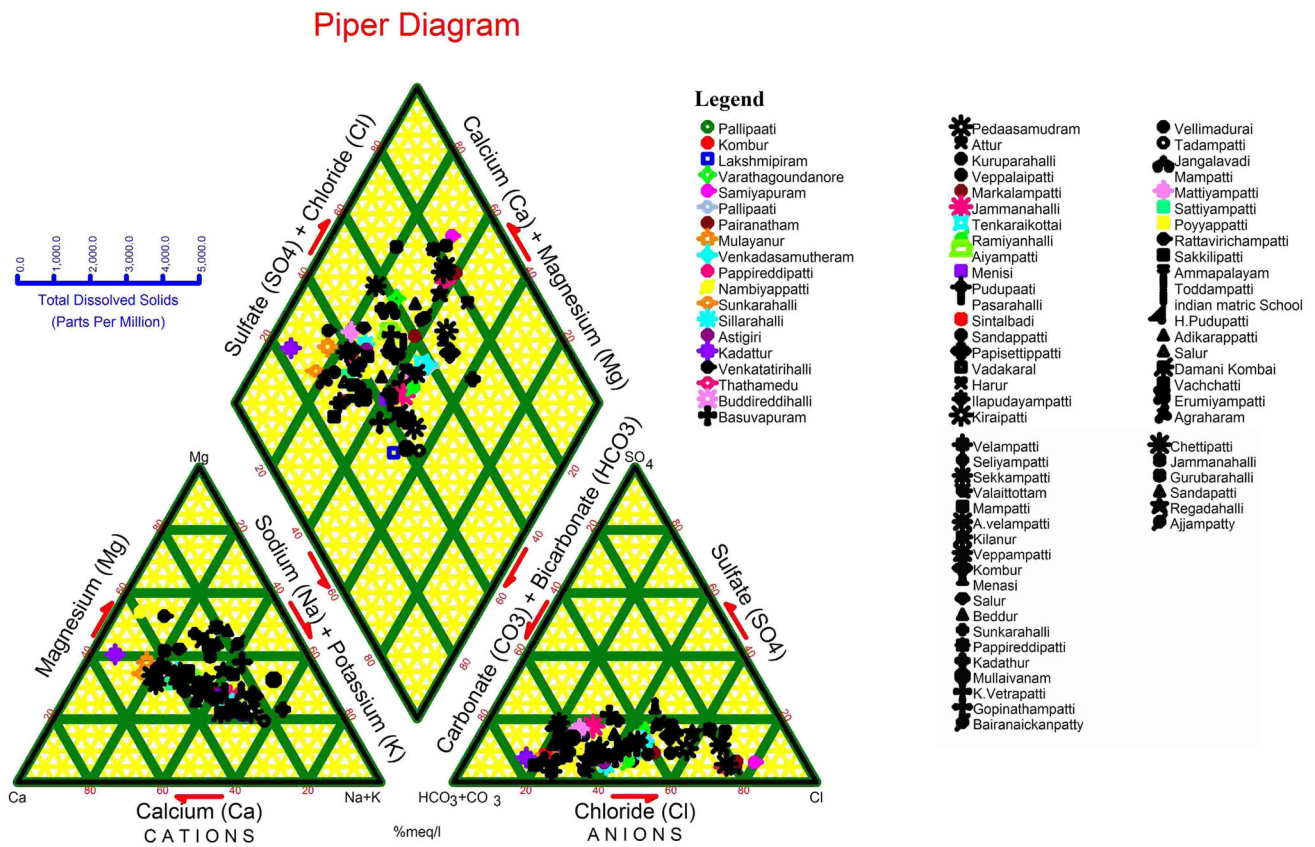


Fig. 9 Piper diagram in ppm

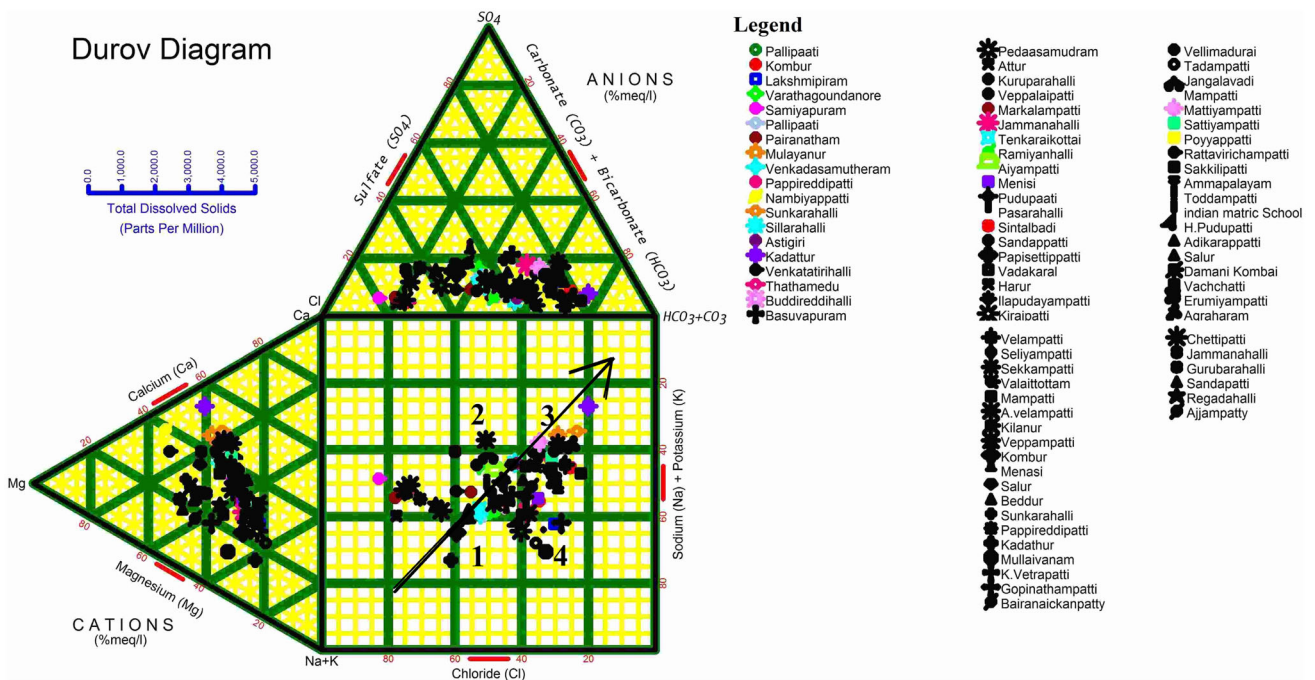
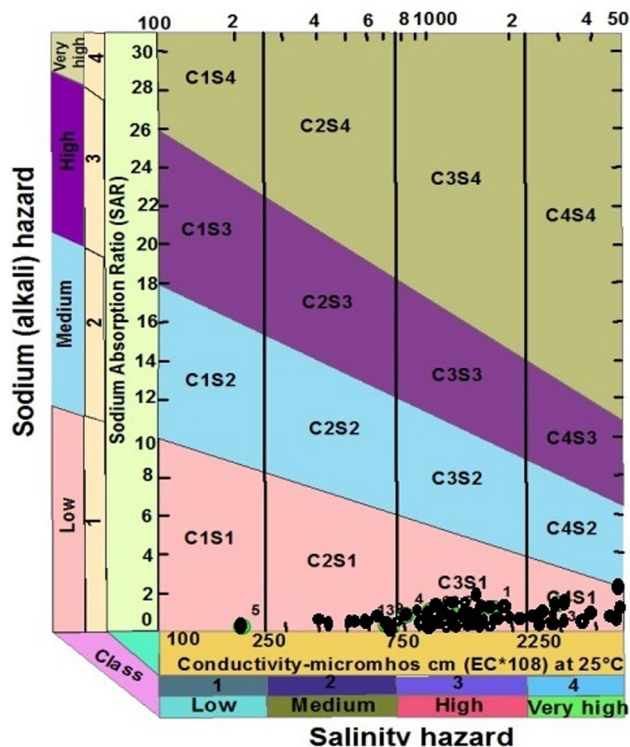


Fig. 10 Durov diagram in ppm

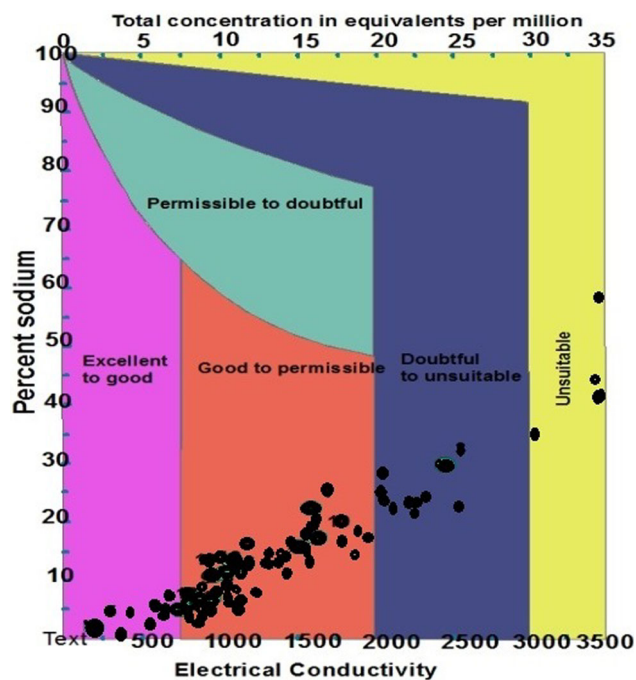
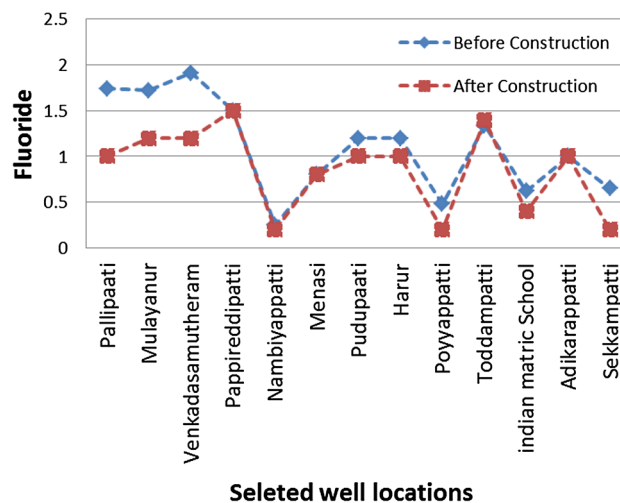
Table 2 Classification of waters based on sodium adsorption ratio values

SI No	SAR values	Remark	Groundwater character
1	<10	Excellent	All well samples
2	10–18	Good	–
3	19–26	Doubtful	–
4	>26	Unsuitable	–

**Fig. 11** US salinity hazard diagram**Table 3** Sodium % water class (Wilcox 1955)

SI No	Na %	Water class	% of samples
1	<20	Excellent	8
2	20–40	Good	85
3	40–60	Permissible	5
4	60–80	Doubtful	2
5	>80	Unsuitable	–

Todampatti, or Adhikarapatti. TDS within the permissible limit is evidence that artificial recharge of groundwater improved water quality in the sub-basin.

**Fig. 12** Classification based on the Wilcox plot**Fig. 13** Fluoride concentration in groundwater (before and after ARS)

3.9 Effect of groundwater quality on check dam and percolation pond

Sample locations closer to ARS showed dilution of TDS and fluoride in the rainy season (Figs. 16, 17, 18, 19, 20, 21). Fluoride levels between 0.3 and 2.6 ppm were observed in Kadattur. Away from the check dam, fluoride concentrations were higher due to gneissic rocks, the weathering zone, and water level fluctuation; closer to the

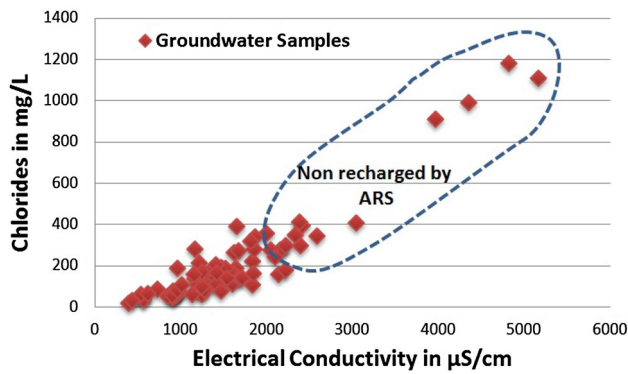


Fig. 14 EC versus chloride concentration of the groundwater samples (after ARS)

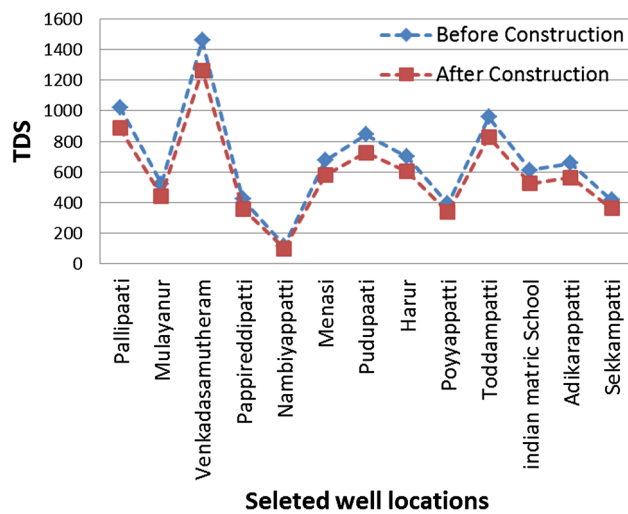


Fig. 15 Variation in TDS in selected wells before and after ARS construction (ppm)

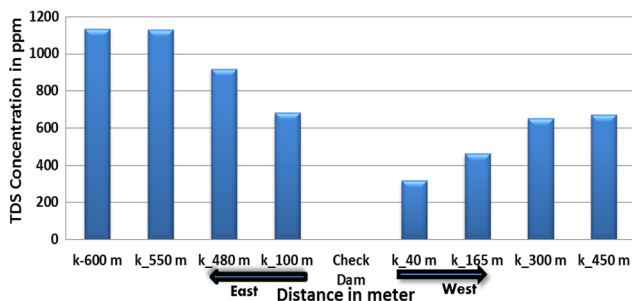


Fig. 16 TDS in ppm at Kadattur

check dam, the fluoride concentrations were lower due to recharge of rainwater.

3.10 Field investigation

ARS were investigated in the field for functional character of the check dam and percolation pond and monitored for impact of recharge in groundwater as shown in Figs. 22 and 23.

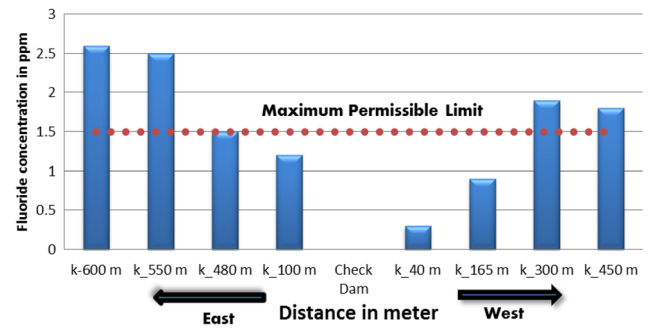


Fig. 17 Fluoride concentration in ppm at Kadattur

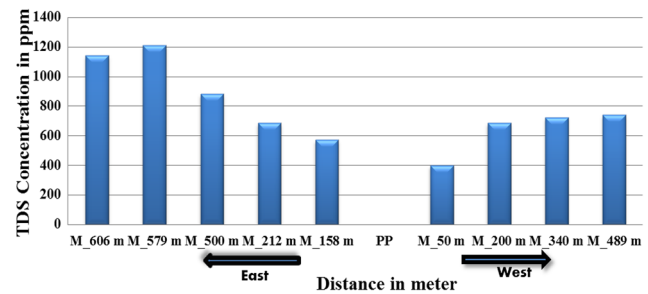


Fig. 18 TDS concentration in ppm at Mookkaredipatti

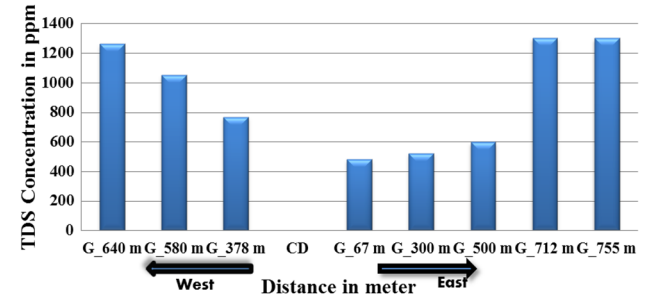


Fig. 19 Showing TDS in ppm at Goundampatti

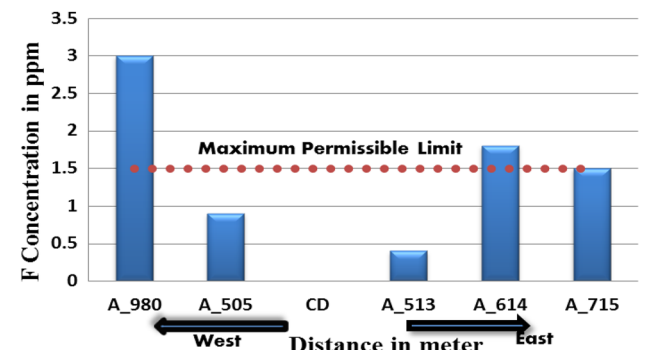


Fig. 20 Fluoride in ppm at Adhikarappatti

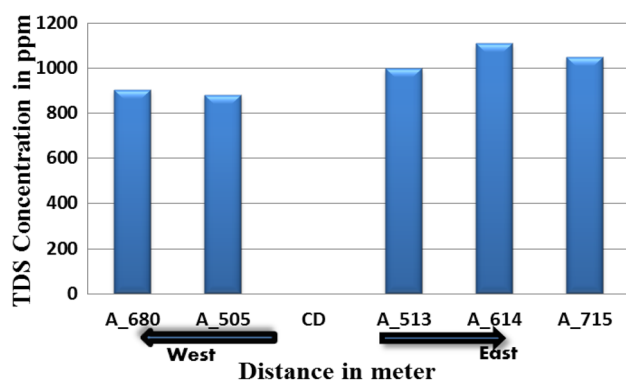


Fig. 21 TDS in ppm at Adhikarapatti

3.11 Dental fluorosis

The prescribed range of fluoride in water for consumption is set to avoid conditions that lead to detrimental dental fluorosis in humans and animals (WHO 2004). People living in high-fluoride regions are certain to get dental staining. Teeth become dull, and yellow-white spots appear on the surface of teeth. Gradually, these spots turn brown and present as brown streaks closer to the tips of the teeth. In late stages, entire teeth become black. Teeth may be pitted or perforated and may even chip. In endemic zones, people lose their teeth at an early age (Fig. 24). Jagadeshan (2015) point out fluoride is naturally present due to weathering of rocks rich in fluoride, especially in type II wells. Groundwater from crystalline rocks, especially

Fig. 22 Check dam during hot (left) and rainy (wet) seasons at Puthupatti



Fig. 23 Percolation Pond during hot (left) and rainy (wet) seasons at Adhikarapatti



Fig. 24 Severe mottling of adult teeth at A.Pallipatti (left); very mild mottling of adult teeth at Kadathur farther away from check dam (Pudureddur)-age 15



granites and gneisses are particularly likely to contain fluoride-bearing minerals.

4 Conclusion

The quality of groundwater in and around selected ARS was evaluated for drinking and irrigation purposes. Silting in percolation ponds and check dams not only decreases the storage capacity but also reduces recharge in the sub-basin. ARS had greater effects downstream as compared to upstream in the sub-basin. The TDS of water is significantly less at the recharge structure and increases with distance due to dilution caused by ARS. The check dam and nearby wells in fluoride-affected areas showed a significant decrease in fluoride concentration, suggesting that recharge methods are effective in reducing fluorosis. The life of percolation tanks and check dams depend on desilting by a geomorphologic agent. The success of recharge structures in Vaniyar sub-basin could be assessed in relation to height of water mound formed, areal extent of water spread both upstream and downstream of the structure, and water quality limits such as TDS and fluoride. With the installation of more recharge structures, there is a need to systematically evaluate their success.

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